Claims:

1. A method of characterizing a device having a plurality of device ports comprising the steps of:
establishing a device S-parameter matrix (S_D) to represent electrical behavior of said device, an adapter T-parameter matrix (T_a) to represent all possible electrical paths through one or more circuits to all of the device ports, and a cascaded S-parameter matrix (S_c) to represent said one or more circuits cascaded with said device,
obtaining values for said adapter T-parameter matrix to represent electrical behavior of said one or more circuits,
measuring said device cascaded with said one or more circuits to obtain values for said cascaded S-parameter matrix, and
solving for said device S-parameter matrix as a function of said adapter T-parameter matrix and said cascaded S-parameter matrix.

2. A method of characterizing as recited in claim 1 wherein said device S-parameter matrix represents an N-port device and said adapter T-parameter matrix represents a 2N-port adapter connected to said device.

3. A method of characterizing as recited in claim 2 wherein said step of measuring said one or more circuits further comprises establishing an adapter

S-parameter matrix to represent said all possible paths through said one or more circuits to said all of the device ports, measuring to obtain values for said adapter S-parameter matrix, and converting said resulting S-parameter matrix to said adapter T-parameter matrix.

4. A method of characterizing as recited in claim 3 wherein said step of solving further comprises the steps of:
partitioning said adapter S-parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices,
converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) transmission parameter sub-matrix, and
solving for said device S-parameter matrix using the equation:

$$(T_{a11} - S_c T_{a21})^{-1}(S_c T_{a22} - T_{a12}).$$

5. A method of characterizing as recited in claim 1 wherein said one or more circuits is represented by a single adapter and further comprising the step of assigning a matrix index to each device port for representing an electrical relationship between all device ports and assigning a matrix index to adapter ports for representing an electrical relationship between all adapter ports.

6. A method of characterizing as recited in claim 5 and further comprising the step of relating said adapter port indexes to a measurement port.

7. A method of characterizing as recited in claim 1 wherein there is an odd number of device ports.

8. A method of characterizing as recited in claim 7 wherein said step of establishing said adapter T-parameter matrix comprises modeling said device with an additional device port and including as part of said adapter T-parameter matrix for said one or more circuits values that represent a zero length, loss-less transmission line connected to said additional device port and terminated in a perfect load.

9. A method of characterizing as recited in claim 7 wherein said step of modeling further comprises including said additional device port such that said device T-parameter matrix represents a device having an even number of device ports and said adapter T-parameter matrix represents an adapter having twice as many adapter ports as said device ports.

10. A method of characterizing as recited in claim 7 wherein said cascaded S-parameter matrix comprises scattering parameter variables in as many rows as there are device ports and as many columns as there are device ports, said cascaded S-parameter matrix further comprising an additional row containing zero values for each matrix element in said additional

row and an additional column containing zero values for each matrix element in said additional column.

11. A method of characterizing as recited in claim 7 wherein said device S-parameter matrix represents an N-port device and said adapter T-parameter matrix represents a 2N-port adapter where N is an even number.

12. A method of characterizing as recited in claim 11 wherein said step of measuring said one or more circuits further comprises establishing an adapter S-parameter matrix to represent said all possible electrical paths from said measuring device through said one or more circuits including said zero-length, loss-less transmission line, measuring to obtain values for elements that comprise said adapter S-parameter matrix, inserting appropriate values in said adapter S-parameter matrix to represent said zero-length, loss-less transmission line, and converting said resulting S-parameter matrix to said adapter T-parameter matrix.

13. A method of characterizing as recited in claim 12 wherein said step of solving further comprises the steps of:

partitioning said adapter S-parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices,

converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and

fourth (T_{a22}) transmission parameter sub-matrix, and

solving for said device S-parameter matrix using the equation:

$$\left(T_{a11} - S_c T_{21}\right)^{-1}\left(S_c T_{a22} - T_{a12}\right).$$

14. A method of predicting electrical behavior of a device in electrical context with one or more circuits comprising the steps of:

obtaining a device S-parameter matrix (S_D) having matrix elements that characterize high frequency behavior of said device, said device having a number of device ports,

establishing a single adapter T-parameter matrix (T_a) having matrix elements that represent transmission parameters for all possible paths in a combination of the one or more circuits,

partitioning said adapter T-parameter matrix into four sub-matrices,

solving for a cascaded S-parameter matrix (S_c) that represents the one or more circuits cascaded with the device as a function of said four sub-matrices and said device S-parameter matrix, and

verifying resulting values in said cascaded S-parameter matrix against a desired result.

15. A method as recited in claim 14 and further comprising the step of

preparing a design for the device embedded in electrical context with said one or more circuits.

16. A method as recited in claim 14 wherein a model for said one or more circuits has twice said number of device ports.

17. A method as recited in claim 16 wherein said step of partitioning comprises splitting said adapter T-parameter matrix into respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) T-parameter sub-matrix and solving for said cascaded S-parameter matrix using the equation:

$$(T_{a11}S + T_{a12})(T_{a21}S + T_{a22}).$$

18. A method as recited in claim 14 wherein said device has an odd number of device ports.

19. A method of designing as recited in claim 18 wherein said step of establishing said adapter T-parameter matrix comprises modeling said device with an additional device port and including as part of said adapter T-parameter matrix a representation of electrical behavior of a zero length, loss-less transmission line connected to said additional device port and terminated in a perfect load.

20. A method of characterizing electrical behavior of a device having a plurality of device ports, the method comprising the steps of:

establishing a device S-parameter matrix (S_D) having variable elements, establishing a single adapter S-parameter matrix (S_a) that represents all possible paths through one or more circuits cascaded with said device, and a cascaded S-parameter matrix (S_c),

measuring S-parameters for said one or more circuits,

assigning said S-parameters obtained in said step of measuring S-parameters for said one or more circuits to elements that comprise said adapter S-parameter matrix,

measuring S-parameters for a cascaded combination of said device in electrical context with said one or more circuits,

assigning said S-parameters obtained in said previous step of measuring to elements that comprise said cascaded S-parameter matrix, and

solving for said device S-parameter matrix as a function of values in said adapter S-parameter matrix and said cascaded S-parameter matrix.

21. A method of characterizing as recited in claim 20 wherein said device S-parameter matrix represents an N-port device and said adapter S-parameter matrix represents a 2N-port adapter connected to said device, wherein N is an even number.

22. A method of characterizing as recited in claim 21 wherein said step of solving further comprises the steps of:

partitioning said adapter scattering parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices,

converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) transmission parameter sub-matrix, and

solving for said device scattering parameter matrix using the equation:

$$(T_{a11} - S_c T_{a21})^{-1}(S_c T_{a22} - T_{a12}).$$

23. A method of characterizing as recited in claim 20 wherein said step of establishing said adapter S-parameter matrix comprises accommodating a scattering parameter value for all possible paths between said one or more circuits and said embedded device.

24. A method of characterizing as recited in claim 20 and further comprising the step of assigning a matrix index to each device port for representing an electrical relationship between all device ports and assigning a matrix index to all ports of said one or more circuits for representing an electrical relationship between all ports in said one or more circuits.

25. A method of characterizing as recited in claim 24 and further comprising the step of relating said indexes for said ports of said one or more circuits to a measurement port.

26. A method of characterizing as recited in claim 20 wherein said number of device ports is odd.

27. A method of characterizing as recited in claim 26 wherein said cascaded S-parameter matrix comprises scattering parameter variables in as many rows as there are device ports and as many columns as there are device ports, said cascaded S-parameter matrix further comprising an additional row containing zero values for each matrix element in said additional row and an additional column containing zero values for each matrix element in said additional column.

28. A method of characterizing as recited in claim 26 wherein said step of establishing said adapter S-parameter matrix further comprises modeling said device with an additional device port and including as part of said adapter S-parameter matrix for said one or more circuits values that represent a zero length, loss-less transmission line connected to said additional port and terminated in a perfect load.

29. A method of characterizing as recited in claim 28 wherein said step of establishing said adapter S-parameter matrix further comprises establishing said adapter S-parameter matrix to represent said all possible paths through said one or more circuits including said zero-length, loss-less transmission line, and wherein said step of measuring to obtain values for said adapter S-parameter matrix further comprises the steps of inserting appropriate values in certain elements of said S-parameter matrix to represent said zero-length, loss-less transmission line, partitioning said adapter scattering parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices, converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) T-parameter sub-matrix, and solving for said device S-parameter matrix using the equation:

$$(T_{a11} - S_c T_{a21})^{-1}(S_c T_{a22} - T_{a12}).$$

30. An apparatus for characterizing electrical behavior of a device embedded in one or more circuits comprising:
a computing device,
a vector network analyzer,

means executing on said computing device for establishing a device S-parameter matrix to represent the device, an adapter T-parameter matrix to represent all possible electrical paths from said vector network analyzer through said one or more circuits to said device, and a cascaded S-parameter matrix to represent said one or more circuits cascaded with said device,

means for transferring measurements made on said vector network analyzer for said one or more circuits into elements of said adapter T-parameter matrix and for said one or more circuits cascaded with said device into elements of said cascaded S-parameter matrix, and

means for solving for said device S-parameter matrix as a function of said adapter T-parameter matrix and said cascaded S-parameter matrix.

31. An apparatus for characterizing as recited in claim 30 wherein said means executing on said computing device further comprises means for establishing an adapter S-parameter matrix to represent said all possible paths from said vector network analyzer through said one or more circuits to said device, means for transferring measurements made by said vector network analyzer to elements in said adapter S-parameter matrix, and means executing on said computing device for converting said resulting S-parameter matrix to said adapter T-parameter matrix.

32. An apparatus for characterizing as recited in claim 30 wherein said means for solving further comprises

means for partitioning said adapter S-parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices, means for converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) transmission parameter sub-matrix, and means for solving for said device S-parameter matrix using the equation:

$$(T_{a11} - S_c T_{a21})^{-1}(S_c T_{a22} - T_{a12}).$$

33. An apparatus for characterizing as recited in claim 30 wherein said device S-parameter matrix represents a device having a number of device ports and said adapter T-parameter matrix represents an adapter having twice as many adapter ports as said device ports.

34. An apparatus for characterizing as recited in claim 30 wherein said number of device ports is odd.

35. An apparatus for characterizing as recited in claim 34 wherein said cascaded S-parameter matrix comprises scattering parameter variables in as many rows as there are device ports and as many columns as there are device ports, said cascaded S-parameter matrix further comprising an additional row containing zero values for each matrix element in said additional row and an additional column containing zero values for each matrix element in said additional column.

36. An apparatus for characterizing as recited in claim 34 wherein said means for establishing said adapter T-parameter matrix comprises means for modeling said device with an additional device port and including as part of said adapter T-parameter matrix values that reflect a zero length, loss-less transmission line connected to said additional device port and terminated in a perfect load.

37. An apparatus for characterizing as recited in claim 36 wherein said means for measuring said one or more circuits further comprises means for establishing an adapter S-parameter matrix to represent said all possible paths from said measuring device through said one or more circuits including said zero-length, loss-less transmission line, means for measuring to obtain values for said adapter S-parameter matrix and inserting appropriate values to represent said zero-length, loss-less transmission line, and means for converting said resulting S-parameter matrix to said adapter T-parameter matrix.

38. An apparatus for characterizing as recited in claim 30 wherein said vector network analyzer is responsive to instructions from said computing device to performing measurements to obtain values for elements in said adapter T-parameter matrix and said cascaded S-parameter matrix.

39. An apparatus for designing a device embedded in electrical context with one or more circuits comprising:

a computing device,

means for obtaining values for a device S-parameter matrix (S_D) having matrix elements that characterize high frequency behavior of said device, wherein said device S-parameter matrix represents a device having a number of device ports,

means executing on said computing device for establishing a single adapter T-parameter matrix (T_a) having matrix elements that represent transmission parameters for all possible electrical paths in said one or more circuits,

means executing on said computing device for partitioning said adapter T-parameter matrix into four sub-matrices, and

means executing on said computing device for solving a cascaded S-parameter matrix (S_c) that represents the one or more circuits cascaded with the device as a function of said four sub-matrices and said device S-parameter matrix.

40. An apparatus as recited in claim 39 and further comprising means for building said device as embedded in a circuit represented by said single adapter.

41. An apparatus as recited in claim 39 wherein a model for said one or more circuits has twice said number of device ports.

42. An apparatus as recited in claim 41 wherein said means executing on said computing device for partitioning further comprises means on said computing device for splitting said adapter T-parameter matrix into respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) T-parameter sub-matrix and solving for said cascaded S-parameter matrix using the equation:

$$(T_{a11}S_D + T_{a12})(T_{a21}S_D + T_{a22}).$$

43. An apparatus as recited in claim 39 wherein said number of device ports on said embedded device is odd.

44. An apparatus as recited in claim 43 wherein said means for establishing said adapter T-parameter matrix further comprises means for modeling said device with an additional device port and including as part of said values in said adapter T-parameter matrix a zero length, loss-less transmission line connected to said additional device port and terminated in a perfect load.

45. An article of manufacture comprising computer readable storage media including computer software embedded therein that causes a processing unit to perform the method comprising the steps of:

establishing a device S-parameter matrix (S_D) to represent electrical behavior of said device, an adapter T-parameter matrix (T_a) to represent all possible electrical paths through one or more circuits to all of the device ports, and a cascaded S-parameter matrix (S_c) to represent said one or more circuits cascaded with said device,

obtaining values for said adapter T-parameter matrix to represent electrical behavior of said one or more circuits,

measuring said device cascaded with said one or more circuits to obtain values for said cascaded S-parameter matrix, and

solving for said device S-parameter matrix as a function of said adapter T-parameter matrix and said cascaded S-parameter matrix.

46. An article of manufacture as recited in claim 45 wherein said device S-parameter matrix represents an N-port device and said adapter T-parameter matrix represents a 2N-port adapter connected to said device.

47. An article of manufacture as recited in claim 46 wherein said step of measuring said one or more circuits further comprises establishing an adapter S-parameter matrix to represent said all possible paths through said one or more circuits to said all of the device ports, measuring to obtain values for said adapter S-parameter matrix, and converting said resulting S-parameter matrix to said adapter T-parameter matrix.

48. An article of manufacture as recited in claim 47 wherein said step of solving further comprises the steps of

partitioning said adapter S-parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices,

converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) transmission parameter sub-matrix, and

solving for said device S-parameter matrix using the equation:

$$(T_{a11} - S_c T_{a21})^{-1}(S_c T_{a22} - T_{a12}).$$

49. An article of manufacture as recited in claim 45 and further comprising the step of assigning a matrix index to each device port for representing an electrical relationship between all device ports and assigning a matrix index to adapter ports for representing an electrical relationship between all adapter ports.

50. An article of manufacture as recited in claim 45 wherein said number of device ports isodd.

51. An article of manufacture as recited in claim 45 wherein said step of establishing said adapter T-parameter matrix comprises modeling said device with and additional device port and including as part of said adapter T-parameter matrix for said one or more circuits values that represent a zero length, loss-

less transmission line connected to said additional port and terminated in a perfect load.

52. An article of manufacture as recited in claim 51 wherein said step of modeling further comprises including said one or more additional device ports such that said device T-parameter matrix represents a device having an even number of device ports and said adapter T-parameter matrix represents an adapter having twice as many adapter ports as said device ports.

53. An article of manufacture as recited in claim 51 wherein said cascaded S-parameter matrix comprises scattering parameter variables in as many rows as there are device ports and as many columns as there are device ports, said cascaded S-parameter matrix further comprising an additional row containing zero values for each matrix element in said additional row and an additional column containing zero values for each matrix element in said additional column.

54. An article of manufacture as recited in claim 51wherein said device S-parameter matrix represents an N-port device and said adapter T-parameter matrix represents a 2N-port adapter where N is an even number.

55. An article of manufacture as recited in claim 54 wherein said step of measuring said one or more circuits further comprises establishing an adapter S-parameter matrix to represent said all possible

electrical paths from said measuring device through said one or more circuits including said zero-length, loss-less transmission line, measuring to obtain values for elements that comprise said adapter S-parameter matrix, inserting appropriate values in said adapter S-parameter matrix to represent said zero-length, loss-less transmission line, and converting said resulting S-parameter matrix to said adapter T-parameter matrix.

56. An article of manufacture as recited in claim 55 wherein said step of solving further comprises the steps of:

partitioning said adapter S-parameter matrix into first (S_{a11}), second (S_{a12}), third (S_{a21}), and fourth (S_{a22}) sub-matrices,

converting each said sub-matrix into a respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) transmission parameter sub-matrix, and

solving for said device S-parameter matrix using the equation:

$$(T_{a11} - S_c T_{21})^{-1}(S_c T_{a22} - T_{a12})'.$$

57. An article of manufacture as recited in claim 55 wherein said step of establishing a T-parameter matrix comprises accommodating a transmission parameter value for all possible paths between said adapter and said embedded device including a path through said zero-length, loss-less transmission line.

58. An article of manufacture comprising computer readable storage media including computer software embedded therein that causes a processing unit to perform the method comprising the steps of:

obtaining a device S-parameter matrix (S_D) having matrix elements that characterize high frequency behavior of said device, said device having a number of device ports,

establishing a single adapter T-parameter matrix (T_a) having matrix elements that represent transmission parameters for all possible paths in a combination of the one or more circuits,

partitioning said adapter T-parameter matrix into four sub-matrices,

solving for a cascaded S-parameter matrix (S_c) that represents the one or more circuits cascaded with the device as a function of said four sub-matrices and said device S-parameter matrix, and

verifying resulting values in said cascaded S-parameter matrix against a desired result.

59. An article of manufacture as recited in claim 58 and further comprising the step of preparing a design for the device embedded in electrical context with said one or more circuits.

60. An article of manufacture as recited in claim 58 wherein a model for said one or more circuits has twice said number of device ports.

61. An article of manufacture as recited in claim 60 wherein said step of partitioning comprises splitting said adapter T-parameter matrix into respective first (T_{a11}), second (T_{a12}), third (T_{a21}), and fourth (T_{a22}) T-parameter sub-matrix and solving for said cascaded S-parameter matrix using the equation:

$$(T_{a11}S + T_{a12})(T_{a21}S + T_{a22}).$$

62. An article of manufacture as recited in claim 58 wherein said device has an odd number of device ports.

63. An article of manufacture as recited in claim 62 wherein said step of establishing said adapter T-parameter matrix comprises modeling said device with an additional device port and including as part of said adapter T-parameter matrix a representation of electrical behavior of a zero length, loss-less transmission line connected to said additional device port and terminated in a perfect load.